(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 735 652 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
31.05.2000 Bulletin 2000/22

(51) Int Cl.⁷: **H02K 19/10**

(21) Application number: **96301733.0**

(22) Date of filing: **14.03.1996**

(54) Improvements in switched reluctance machines

Geschaltete Reluktanzmaschine

Machine à reluctance commutée

(84) Designated Contracting States:
DE ES FR GB IT NL SE

(30) Priority: **28.03.1995 GB 9506294**

(43) Date of publication of application:
02.10.1996 Bulletin 1996/40

(73) Proprietor: **SWITCHED RELUCTANCE DRIVES LIMITED**
Harrogate, North Yorkshire HG3 1PR (GB)

(72) Inventor: **Fulton, Norman Neilson**
Leeds, LS17 7SX (GB)

(74) Representative: **Hale, Peter et al**
Kilburn & Strode
20 Red Lion Street
London WC1R 4PJ (GB)

(56) References cited:

EP-A- 0 282 292	**FR-A- 2 072 612**
GB-A- 2 262 843	**GB-A- 2 266 196**

- **IEE PROCEEDINGS B. ELECTRICAL POWER APPLICATIONS, vol. 140, no. 1 PART B, 1 January 1993, pages 61-70, XP000304284 MECROW B C: "FULLY PITCHED-WINDING SWITCHED-RELUCTANCE AND STEPPING-MOTOR ARRANGEMENTS"**

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] This invention relates to reluctance machines. The invention is particularly applicable to a switched reluctance machine whether operated as a motor or a generator.

[0002] Reluctance machines are electrical machines which produce torque by the tendency of a moving component of the machine to take up a position in which the reluctance of the magnetic circuit is minimised. Typically, at least one of the stator and rotor members has magnetic saliencies which are normally realised in the form of poles projecting from the member.

[0003] The switched reluctance (SR) machine is a particular form of reluctance machine which has salient poles on both stator and rotor members. In this form, the machine is referred to as a 'doubly salient' machine. The torque or electrical output (depending on whether the machine is run as a motor or a generator) is controlled by a controller which regulates the period during which a stator winding is connected electrically with a source of power.

[0004] SR machines are realised in a variety of forms. In particular, they differ in the number of stator and rotor poles on the stationary and rotating members, respectively, and in the number of independent circuits with which the controller is able separately to switch stator windings in and out of circuit. Each set of windings separately switched in and out of circuit by the controller constitutes one phase of the machine. The machine may have one or more such phases.

[0005] The theory, design and operation of SR machines is well documented, for example in the book 'Switched Reluctance Motors and their Control' by T.J. E. Miller, Clarendon Press, 1993 and the article 'The Characteristics, Design and Applications of Switched Reluctance Motors and, Drives' by Stephenson et al., PCIM '93, June 21-24, 1993.

[0006] Figure 1 shows a known form of SR machine. The stator has six poles (A, A', B, B', C, C') and the rotor four poles. Each stator pole has one coil wound around it. Although only two coils on stator poles A and A' are shown in Figure 1 for the sake of clarity, it will be appreciated that a similar arrangement would be formed in respect of the other pairs of poles. Typically, the coils on diametrically opposite poles are connected together either in series or in parallel (depending on the nature of the application of the machine) to form a phase of the machine. Thus, the machine in Figure 1 is a three-phase machine in which the windings of one phase are switchable independently from those of the other phases. When the machine is operated, each phase is normally connected to a source of electrical power through one or more electronic switches t as shown in Figure 2. The method of operation of such a machine using the switching circuit of Figure 2 will be well known to the skilled person and is documented in the above references.

[0007] In general, the number of poles in a stator is such that each phase has an even number of coils associated with it. In the example of Figure 1, each of the three phases has two coils, so the machine has six stator poles. In the example of Figure 3 each of the three phases are made up of four coils symmetrically disposed around the stator, giving a twelve-pole stator. It will be appreciated that various combinations of numbers of rotor poles and stator poles are possible. The selection of a suitable combination is a matter of design choice for a given application.

[0008] When one phase of the machine in Figure 1 is energised by a voltage being applied to the windings of one of the phases, a magnetic field is set up in the machine. This is shown schematically by the arrowed broken lines in Figure 1. The lines are a representation of the lines of magnetic flux in the machine when phase A is energised. This field pattern is known as a two-pole field pattern since the magnetic flux crosses the air gap of the machine in two principal places.

[0009] Generally, when one phase of the machine of Figure 3 is energised, a magnetic field is set up as represented by the arrowed broken lines. Such an arrangement is known as a four-pole field pattern. By continuing to multiply the number of coils in one phase, field patterns with increasing numbers of poles can be produced. This can be done independently of the number of phases of the machine.

[0010] In a conventional machine having one coil on each pole, the coils are sized so that they can be assembled in turn on the poles without obstructing each other. The coils, and the gaps between poles in which they fit, are generally similar. The coil, when in place, cannot extend angularly past the mid-point between two adjacent stator poles as it would occupy the space available at the expense of the adjacent coil and would also impede insertion of the adjacent coil into its space. Thus, the cross sectional area of a coil side must occupy something less than half the total available cross sectional area between radially projecting adjacent poles. While the machine designer would often wish to make the coil bigger by increasing the cross sectional area to reduce current density and the consequent power loss in the coil, it is not possible to do this without increasing the overall size of the machine.There have been attempts to solve this problems in machines which have a particular phase number or particular lamination shape (e.g. GB-A-2240664 and GB-A-2232305) but these are restricted in their applicability.

[0011] Another approach has been to use the whole of the inter-pole slot for a single coil side by using fully pitched coils (eg as described in "Fully pitched-winding switched-reluctance and stepping-motor arrangements". Mecrow, BC, Proc IEE, Part B, Vol 140, No. 1, Jan 1993, pp 61-70). While this method places a single coil side in an inter-pole slot, the use of fully pitched coils requires a quite different approach to controlling the machine, since the torque-producing mechanism is now due to variations in the mutual inductance between phases, instead of the variation of self inductance of the phase. The conventional controller used with machines having conventional short-pitched coils does not work with this fully pitched arrangement and a completely different, more costly, controller is required.

[0012] It is an object of the present invention to provide a reluctance machine structure that allows a larger coil size to be used in relation to a given pole.

[0013] It is a further object of the invention to provide a reluctance machine that is easier and cheaper to construct than known reluctance machines.

[0014] According to the present invention, there is provided a doubly salient reluctance machine as specified in claim 1 and a method of constructing a doubly salient polyphase reluctance machine as specified in claim 6. Some preferred features are specified in the dependent claims.

[0015] This invention is particularly applicable to switched reluctance machines which have a four-pole field pattern (or integral multiples of four) and an odd number of phases. However, the invention' may also be used on other arrangements of reluctance machines including two-phase machines. Preferably, the invention consists of placing coils on only one stator pole of a pole pair in the machine. The coils can be designed so that the machine produces the same performance as it would have had if the conventional design practice of placing a coil on both stator poles in a pair had been adopted. Because only one pole in a pair is arranged with a winding, the motor can be designed such that poles adjacent to that bearing the winding do not have windings associated with them. Thus, the space available for the winding is substantially increased as each space between poles can be used exclusively for a single winding.

[0016] The invention can be put into practice in various ways, some of which will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a schematic cross section through a conventional reluctance machine;
Figure 2 is a circuit diagram showing the principal power handling components of a switching circuit for the machine of Figure 1;
Figure 3 is a schematic cross section through a further form of conventional reluctance machine;
Figure 4 is a schematic cross section through a reluctance machine according to a first embodiment of the invention; and
Figure 5 is a schematic cross section through a reluctance machine according to a further embodiment of the invention.

[0017] Referring to Figure 4 of the drawings, a doubly salient reluctance machine comprises a stator 10 defining twelve equiangularly spaced stator poles 12. For the sake of clarity an eight-pole rotor is not shown in Figure 4. However, it will be clear to the skilled person that such a rotor would be arranged as in Figure 3, to rotate within the stator 10.

[0018] The stator 10 is fitted with three phase windings ϕA, ϕB, ϕC comprising pairs of coils 16 embracing diametrically opposing stator poles 12 so that alternate stator poles do not have a coil. In this example, the coils 16 in a phase are serially connected between terminals 18 of the phases ϕA, ϕB and ϕC. In an alternative embodiment, the coils are connected in parallel.

[0019] Each of the phases is shown as terminating in the terminals 18. For the machine to operate either as a motor or as a generator, these terminals would be switchably connected with a power supply through a controller such that control of the application of a voltage to each of the phases in sequence will produce the required power flow. It will be apparent to the skilled person that the switched reluctance machine uses the same circuit for motoring or generating, only the timing of the voltage pulses changes to alter the direction of power flow from/to the supply.

[0020] It will be seen from inspection of Figure 3 that the flux pattern is set up in the circuit of a reluctance machine by the magnetomotive force (MMF) produced by the four coils of a conventional four-pole machine. If, say, coil J of Figure 3 were to be placed around coil H and coil L were to be placed around coil K, the total MMF being applied to the magnetic circuit would be unchanged. If then coils H and J were combined into one coil, with the same number of turns as coils H and J in total, and also coils K and L are similarly combined, the machine has the form shown in Figure 4 which is according to the invention. The machine only has coils on alternate poles of the phase, but has substantially the same performance as the machine of Figure 3.

[0021] In Figure 5 a doubly salient reluctance machine according to the invention derived from that in Figure 1 is shown. A stator 20 defines six stator poles 22 and a rotor 24 defines four rotor poles 26. Again, the pair of coils associated with each of the three phases ϕA, ϕB, ϕC is combined in coils 28 on one stator pole of a pair in a 2-pole field pattern. The coil in the inventive machine would be arranged to provide the same ampere-turns as a conventional machine for substantially the same performance. However, there is a disadvantage in this 2-pole field pattern arrangement in that the coils which remain are still adjacent each other.

[0022] The present invention can be implemented to best effect on switched reluctance machines having an odd number of phases and a field pattern with an integral multiple of four poles. Because of the geometry of the stator in such a machine, it will be seen that, if the coils are laid out on the poles according to the invention, the alternate coils in the phases are on alternate poles in the stator. This in turn allows the coils to be considerably bigger because of the alleviated space restriction. Even though the coils have twice as many turns as they would have had in a conventional machine they can maintain, or even have increased, the cross-sectional area per turn. This enables an equivalent machine to operate with at least no degradation of performance for the four-pole field pattern. In addition, there are manufacturing advantages since there are half the coils to wind, half the poles to insulate and half the phase connections to make. This leads to both cost reductions and increased reliability through a reduced component current.

[0023] It will be appreciated by the skilled person that, while the invention is described in relation to rotary machines, it is equally applicable to linear reluctance machines. In a linear machine the moving member is often still referred to as a rotor. The term rotor, as used here, is intended to embrace such rotors of linear machines. Again, the space created by the absence of pairs of coils in the same slot between stator poles can be used to the same advantage. The reduced number of connections, coils and insulating components in the coil arrangement of this invention will reduce manufacturing costs and time.

[0024] While the invention has been described in connection with the illustrative embodiments discussed above, those skilled in the art will recognise that many variations may be made without departing from the present invention. For example, the present invention is applicable to inverted machines in which the stator is in the centre of the machine and the rotor is arranged to rotate around the outside of the stator. Accordingly, the above description of several embodiments is made by way of example and not for the purposes of limitation. The present invention is intended to be limited only by the scope of the following claims.

Claims

1. A doubly salient polyphase reluctance machine comprising

   a stator (10) defining stator poles (12),
   a rotor defining rotor poles, n pairs of the rotor poles being simultaneously alignable with a corresponding n pairs of the stator poles (12) as the rotor moves relative to the stator (10), where n is an integer greater than zero,
   a phase winding comprising one or more coils (16) provided on each of half of the stator poles (12), the or each coil (16) embracing only one pole and the phase winding being energisable to produce flux in a magnetic circuit having a path that includes the said n pairs of rotor and stator poles (12) and defines a field pattern having 2n poles.

2. A machine as claimed in claim 1 in which n = 1 and the flux path defines a two-pole field pattern, the pair of stator poles (12) being substantially diametrically opposed.

3. A machine as claimed in claim 1 in which n = 2 and the flux path defines a four-pole field pattern, the two coils (16) in each phase winding being substantially diametrically opposed.

4. A machine as claimed in claim 1 in which n is greater than 1 and in which the coils (16) comprising each phase winding are connected in series.

5. A machine as claimed in claim 1 in which n is greater than 1 and in which the coils (16) comprising each phase winding are connected in parallel.

6. A method of constructing a doubly salient polyphase reluctance machine comprising a stator (10) defining stator poles (12), a rotor defining rotor poles, n pairs of the rotor poles (12) being simultaneously alignable with a corresponding n pairs of the stator poles (12) as the rotor moves relative to the stator (10), where n is an integer greater than zero, the method comprising

   forming a phase winding comprising one or more coils (16) on each of half of the stator poles (12), the or each coil (16) embracing only one pole (12) and being energisable to produce flux in a magnetic circuit whose path includes the said n pairs of rotor and stator poles (12) and defines a field pattern having 2n poles.

Patentansprüche

1. Doppelt ausgeprägte Mehrphasenreluktanzmaschine mit

   einem Stator (10), der Statorpole (12) definiert,
   einem Rotor, der Rotorpole definiert, wobei n-Paare der Rotorpole gleichzeitig mit entsprechenden n-Paaren von Statorpolen (12) ausrichtbar sind, wenn sich der Rotor relativ zu dem Stator (10) bewegt, wobei n eine ganze Zahl größer als 0 ist,
   und mit einer Phasenwicklung, die eine oder mehrere Spulen (16) umfaßt, die auf jeder Hälfte der Statorpole (12) vorgesehen sind, wobei die oder jede Spule (16) nur einen Pol umfaßt und die Phasenwicklung erregbar ist, um in einem magnetischen Kreis einen Fluß zu erzeugen, der einen Pfad aufweist, der die n-Paare von Rotor- und Statorpolen (12) beinhaltet und ein Feldmuster mit 2n-Polen definiert.

2. Maschine nach Anspruch 1, bei welcher n = 1 und der Flußpfad ein zwei-poliges Feldmuster definiert, wobei das Paar von Statorpolen (12) im wesentlichen diametral gegenüberliegend ist.

3. Maschine nach Anspruch 1, bei welcher n = 2 und

der Flußpfad ein vierpoliges Feldmuster definiert, wobei die zwei Spulen (16) in jeder Phasenwicklung im wesentlichen diametral gegenüberliegend sind.

4. Maschine nach Anspruch 1, bei welcher n größer als 1 ist und bei welcher die Spulen (16), die jede Phasenwicklung umfassen, in Serie geschaltet sind.

5. Maschine nach Anspruch 1, bei welcher n größer als 1 ist und bei welcher die Spulen (16), die jede Phasenwicklung umfassen, parallel geschaltet sind.

6. Verfahren zur Herstellung einer doppelt ausgeprägten Mehrphasenreluktanzmaschine mit einem Stator (10), der Statorpole (12) definiert, einem Rotor, der Rotorpole definiert, wobei n-Paare von Rotorpolen (12) gleichzeitig mit entsprechenden n-Paaren von Statorpolen (12) ausrichtbar sind, wenn der Rotor sich relativ zu dem Stator (10) bewegt, wobei n eine ganze Zahl größer als 0 ist, und wobei das Verfahren das Bilden einer Phasenwicklung umfaßt, die eine oder mehrere Spulen (16) auf jeder Hälfte der Statorpole (12) umfaßt, wobei die oder jede Spule (16) nur einen Pol (12) umfaßt, und erregbar ist, um in einem magnetischen Kreis einen Fluß zu erzeugen, dessen Pfad die n-Paare von Rotor und Statorpolen (12) beinhaltet und ein Feldmuster definiert, das 2n-Pole aufweist.

Revendications

1. Machine à réluctance doublement saillante et polyphasée qui comporte

   un stator (10) définissant des pièces polaires (12) de stator,
   un rotor définissant des pièces polaires de rotor, n paires de ces pièces polaires de rotor étant susceptibles d'être simultanément alignées sur un nombre n correspondant de paires de ces pièces polaires (12) de stator lorsque le rotor se déplace par rapport au stator (10), où n est un nombre entier supérieur à zéro,
   un enroulement de phase qui comporte un ou plusieurs bobinages (16) disposés sur chaque pièce polaire faisant partie d'une moitié de l'ensemble des pièces polaires (12) du stator, ce bobinage ou chaque bobinage (16) enserrant seulement une pièce polaire et cet enroulement de phase étant susceptible d'être excité de façon à créer un flux dans un circuit magnétique ayant un trajet qui comprend lesdites n paires de pièces polaires de rotor et de stator (12) et qui définit une trame de champ magnétique comportant 2n pôles.

2. Machine telle que revendiquée par la revendication 1 dans laquelle n = 1 et le trajet du flux définit une trame de champ magnétique à deux pôles, les pièces polaires de la paire de pièces polaires (12) du stator étant sensiblement diamétralement opposées.

3. Machine telle que revendiquée par la revendication 1 dans laquelle n = 2 et le trajet du flux définit une trame de champ magnétique à quatre pôles, les deux bobinages (16) situés dans chaque enroulement de phase étant sensiblement diamétralement opposés.

4. Machine telle que revendiquée par la revendication 1 dans laquelle n est supérieur à 1 et dans laquelle les bobinages (16) que comporte chaque enroulement de phase sont connectés en série.

5. Machine telle que revendiquée par la revendication 1 dans laquelle n est supérieur à 1 et dans laquelle les bobinages (16) que comporte chaque enroulement de phase sont connectés en parallèle.

6. Procédé de construction d'une machine à réluctance doublement saillante et polyphasée qui comporte un stator (10) définissant des pièces polaires (12) de stator, un rotor définissant des pièces polaires de rotor, n paires de ces pièces polaires de rotor étant susceptibles d'être simultanément alignées sur un nombre n correspondant de paires de ces pièces polaires (12) de stator lorsque le rotor se déplace par rapport au stator (10), où n est un nombre entier supérieur à zéro, ce procédé comportant
   la constitution d'un enroulement de phase qui comporte un ou plusieurs bobinages (16) situés sur chaque pièce polaire faisant partie d'une moitié de l'ensemble des pièces polaires (12) du stator, ce bobinage ou chaque bobinage (16) enserrant seulement une pièce polaire (12) et étant susceptible d'être excité de façon à créer un flux dans un circuit magnétique dont le trajet comprend lesdites n paires de pièces polaires de rotor et de stator (12) et définit une trame de champ magnétique comportant 2n pôles.

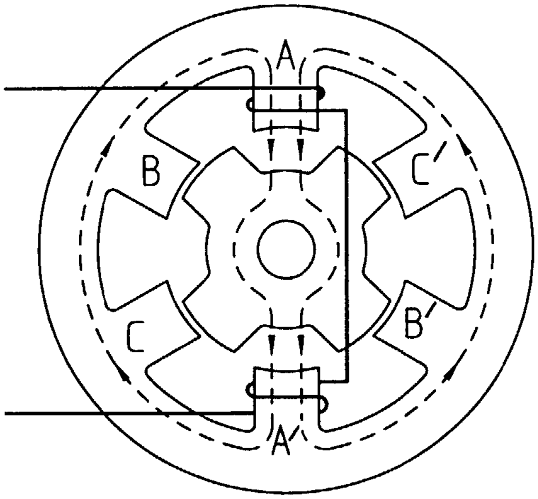

FIG.1. Prior Art

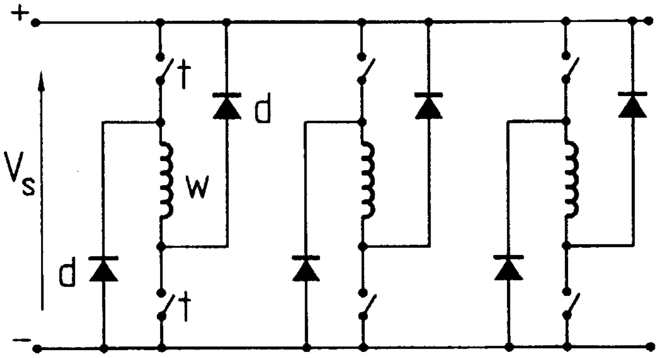

FIG.2. Prior Art

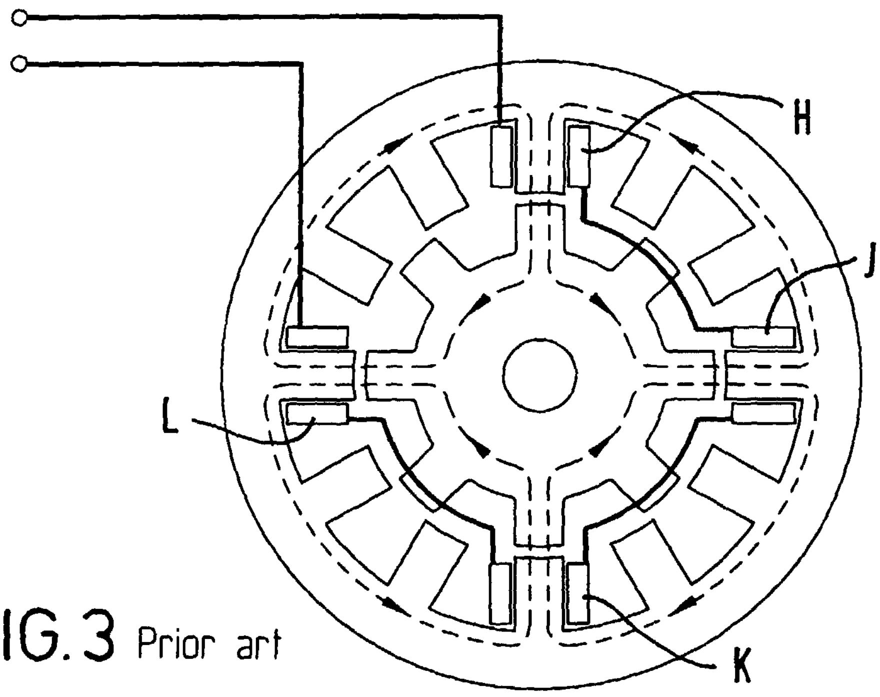

FIG. 3 Prior art

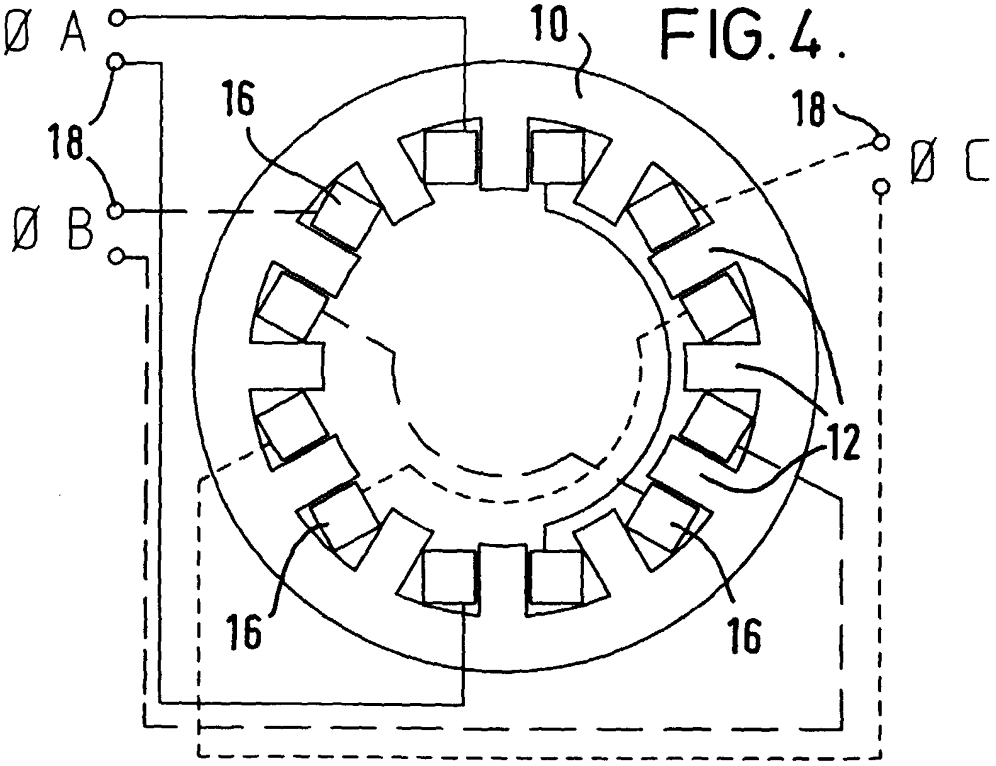

FIG. 4.

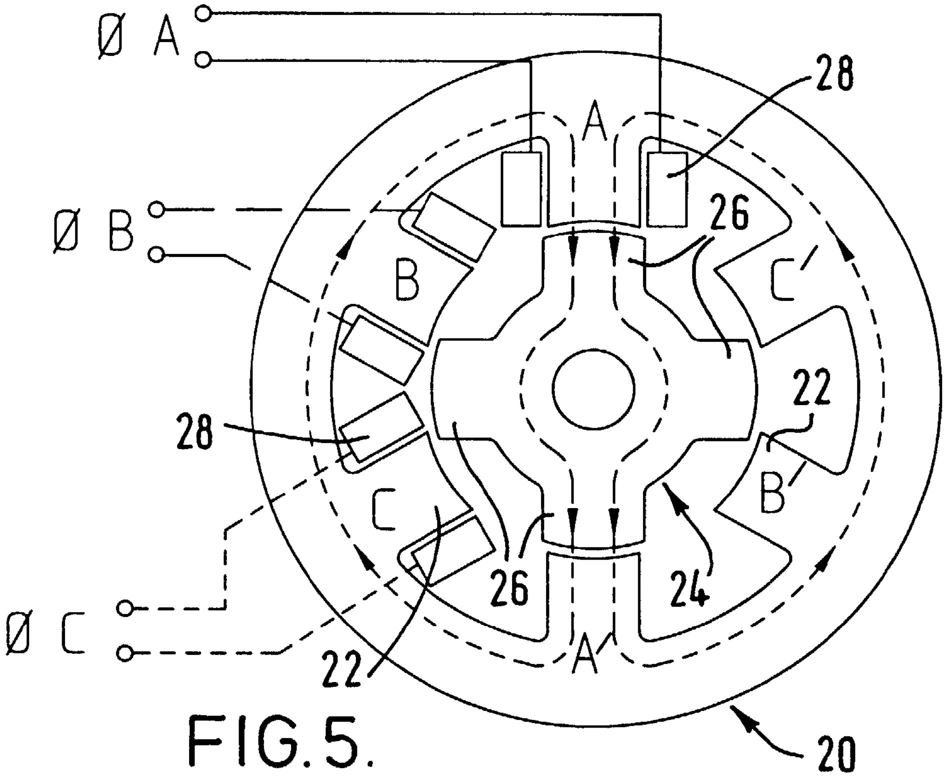

FIG.5.